Office of the Secretary of Defense

Defense Microelectronics Activity (DMEA)

Will technology bite back?

Looking at new impacts on DoD microelectronics

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Outline

Will Technology Bite Back ?

Tin Whisker Failures

Lead-free Impacts

Atmospheric Radiation Effects

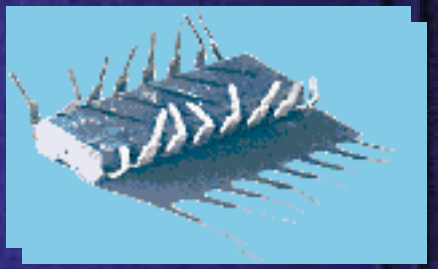
COTS

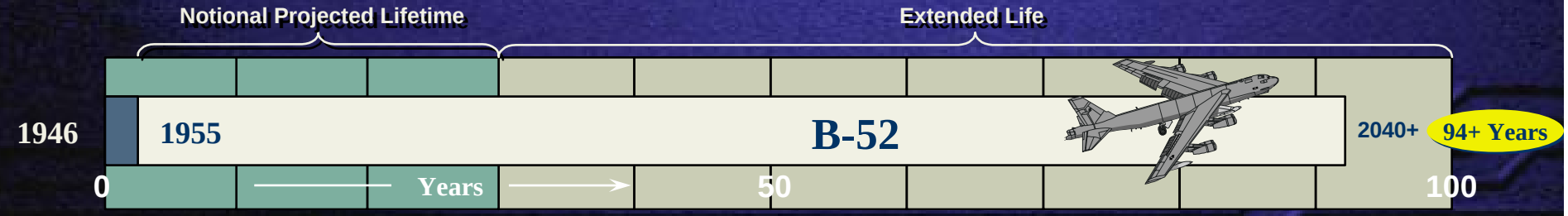
Semiconductor Reliability

"Snakes in the Cockpit" *with permission of JCAA & Hank Caruso*

The Microelectronics Challenge

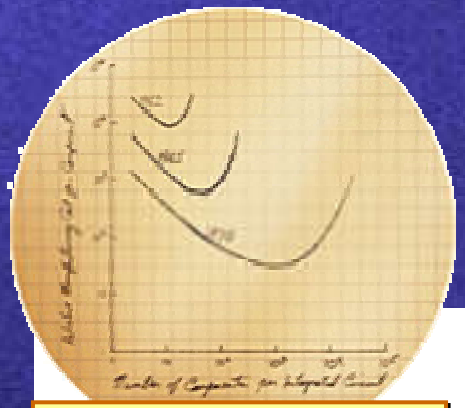
- DoD relies on microelectronics technology
  - "Smart" weapon systems
  - Critical to strategic, tactical, C4I
  - Low volumes
  - Long development cycles
  - VERY long product lifecycles
- But… Consumers (COTS) drive markets
  - High volumes
  - Short production lifecycles
  - Throw-away electronics
  - 2 year technology nodes



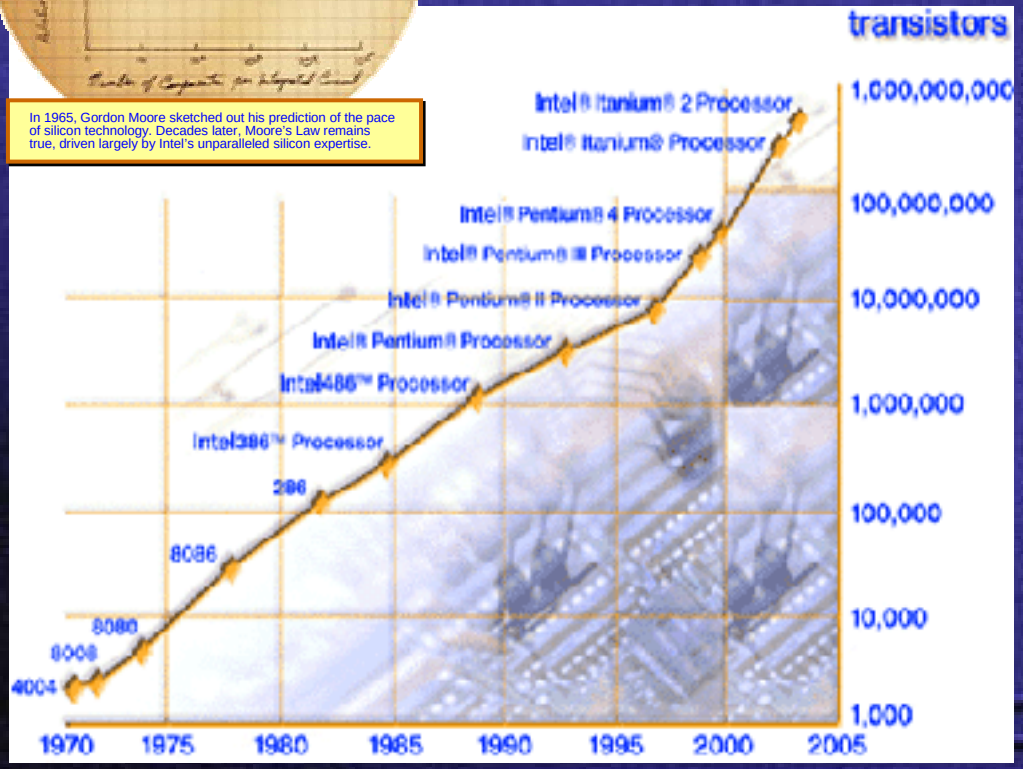


Moore's Law

In 1965 Gordon Moore hypothesized that the number of transistors on a chip would double about every two years.



In 1965, Gordon Moore sketched out his prediction of the pace of silicon technology. Decades later, Moore's Law remains true, driven largely by Intel's unparalleled silicon expertise.



Decades later… technical innovation continues to overcome all technical barriers

2005+ vs. 1995

- **Lithography methods**
- **Cu vs. Al interconnects**
- **Metal vs. Polysilicon gate**
- **High k vs. SiO_2 gate insulator**
- **Low k vs. SiO_2 dielectrics**
- **SOI vs. Silicon substrate**
- **Strained Si vs. Silicon channel**

Will Technology Bite Back ?

Lead-free Impacts

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Lead-Free Impacts

There is a global transition to lead-free

- Lead-free brings new and re-emerging failure modes in electronics
- Reduction of Hazardous Substances (RoHS)
  - EU Directive banning "placing on market" new electronic equipment containing specific levels of the following after July 1, 2006
    - **Lead**, Cadmium, Mercury, hexavalent chromium, polybrominated biphenyl (PBB), polybrominated diphenyl ether (PBDE) flame retardants
- Waste Electrical and Electronic Equipment Directive (WEEE)
  - EU directive aims to minimize the impact of electronic waste
  - Encourages and sets criteria for collection, treatment, recycling
  - Makes the *producer responsible*
- Related legislation underway in China and Japan

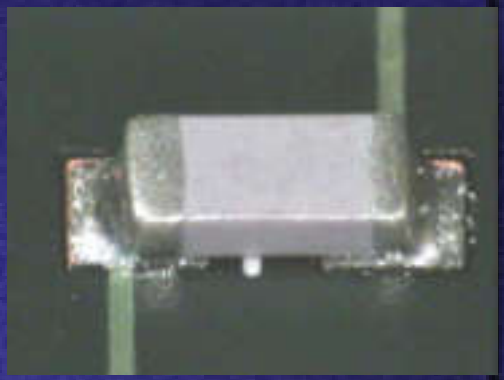
Lead-free Impacts on DoD

- DoD (and Aerospace) systems have unique requirements
  - High reliability
  - VERY long service life
  - Extended temperature ranges
  - We still *repair* boards!
- Primary Lead-free impacts
  - Lead-free solder/components
  - Tin whisker failures
  - New processes / configuration control
  - Availability of leaded solder and components

Commercial solution strategies for lead-free assembly do not necessarily apply to Military / Aerospace applications

Lead-free Solder Issues

- Temperature stress
  - Prevailing Pb-free solder replacement (SnAgCu) has ***35°C higher*** reflow temperature
  - Infant mortality
  - Latent failures
  - Requalification?
- Solder joint reliability (durability)
  - Intermetallics between solder and lead/pad
  - Cross contamination of different alloys
  - Changed / unacceptable wetting characteristics
- Patent infringement
  - Due to mixed alloys during repair or manufacture
- Configuration control
  - Must prevent mixing of incompatible alloys



Cracked Solder Joint

Tin Whisker Failures

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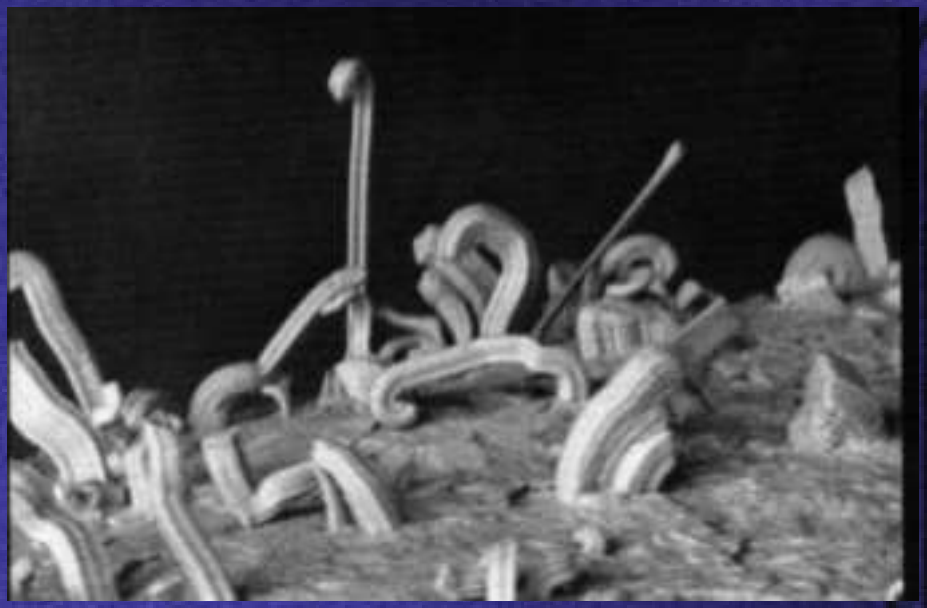
Tin Whisker Impacts

- Tin whisker effects documented since the 1940's
- Tin Whiskers
  - "grow" from nearly all tin alloys
  - Electrically conductive
  - Crystalline
- Whisker induced failures
  - *Short Circuit* – bridges two adjacent pins
  - *Metal vapor arc* – high voltage and specific atmosphere can result in plasma arc capable of catastrophic damage
  - *Contamination* – whisker breaks off and interferes with mechanical, optical, or MEMS component



(Photo courtesy of NASA Goddard Space Flight Center)

Lead-Free Mitigation Efforts

Lead-free Electronics in Aerospace Project (LEAP) Working Group

- Members from GEIA, AIA, AMC, Industry, Government
- Developing 4 guidance documents for Military and Aerospace use (and non-use) of lead-free components
- International Electrotechnical Commission (IEC) TC-107 has formed a task group to submit these documents for international standards consideration

Common resolution strategies and process will save $$ and reduce risk

Mil / Aero Lead-free Efforts

- University of Maryland - CALCE
  - Computer Aided Life Cycle Engineering (CALCE) Electronic Products and Systems Center (EPSC)
  - Several projects and tools related to lead-free and tin whisker
- NASA – Goddard Space Flight Center
  - Extensive research and documentation on tin whisker effects
  - Check out the pictures!
- Navy – ONR
  - Office of Naval Research (ONR)
  - Best Manufacturing Practices Center of Excellence (BMPCOE)
  - Ongoing tin whisker research with Raytheon, CALCE, NASA, Boeing, Honeywell, Northrop Grumman

Tin Whisker Mitigation Techniques

- There has been considerable research to characterize tin whisker growth
  - None can STOP tin whisker formation (on any Sn alloy)
  - Few can predict tin whisker growth
  - Exact cause of whisker growth still a debate

- Documented methods to *reduce* tin whisker effects
  - AVOID the use of PURE TIN (!)
  - Solder-dip with SnPb
  - Strip and replate
  - Underplate with Ni
  - Control the plating process
  - Conformal coating

Atmospheric Radiation Effects

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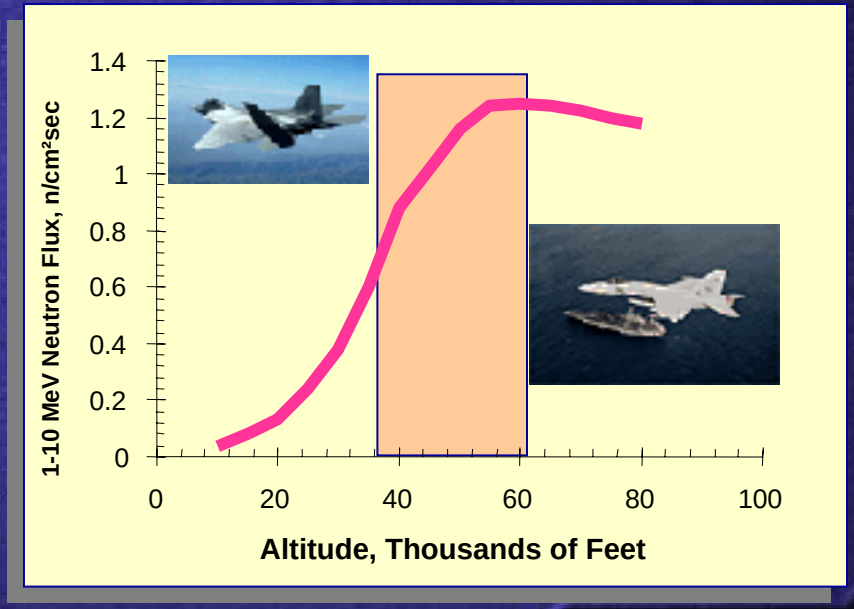
Atmospheric Radiation Effects

- Neutron Single Event Effects (SEE)
- Documented failures at ground and aircraft altitudes
- NOT “Nuke” radiation
- NOT “Space” radiation (RAD-Hard)



Atmospheric Radiation Effects

- Modern fine feature size devices are more susceptible
- Memory and microprocessors are vulnerable

Technology Node, nm	Sensitive Volume (Si), μ^3	Sensitive Depth (SOI), μ	Critical Charge (Si), fC
250	0.245	0.15	8
130	0.025	0.15	2.5
90	0.01	0.07	1.2
65	0.0035	0.05	0.8

P. Roche, G. Gasiot, K. Forbes, V. O'Sullivan, V. Ferlet, "Comparisons of Soft Error Rate for SRAMs in Commercial SOI and Bulk Below the 130 nm Technology Node," 2003 IEEE Nuclear and Space Radiation Effects Conference.

Test "portability" is not assured

Current estimates for SEU rates are probably conservative by >2x

Semiconductor Reliability

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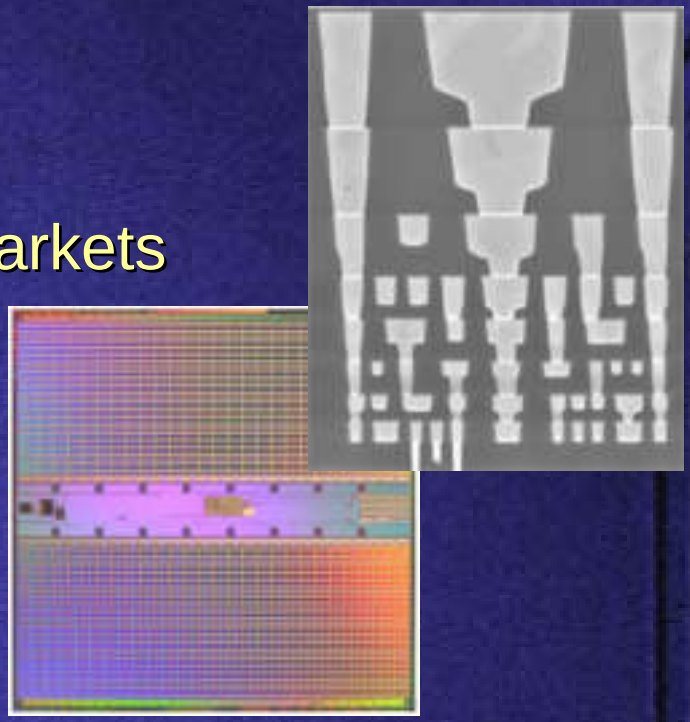
DoD IC Reliability concerns

- COTS ICs in a MIL environment
- VERY long service life
- Use of parts outside intended markets
- Less manufacturer support
  - DoD is a “small player”
  - Competition sensitivity
  - Proprietary processes
- Reduced margins
- Questionable reliability calculation methods

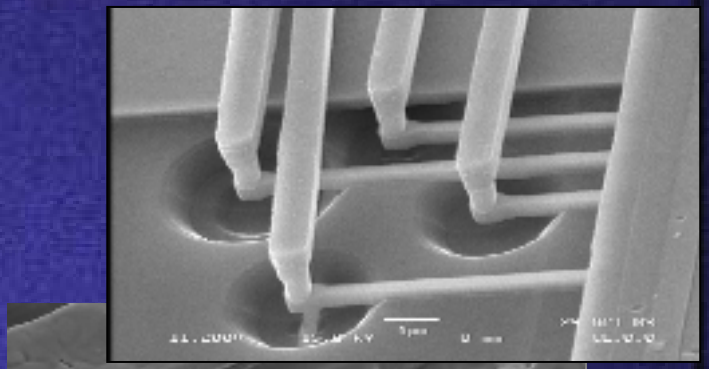


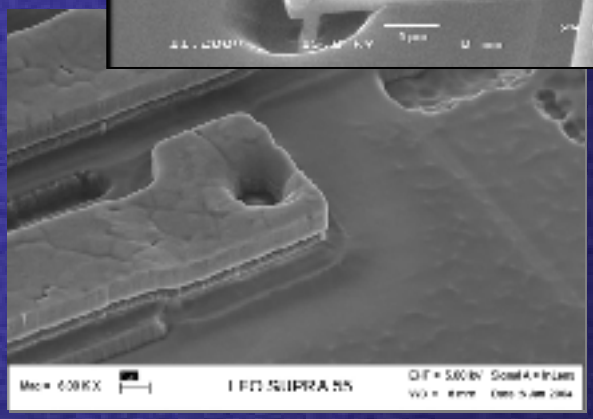
“Margin is performance left on the table”

Steve Huber, Intel, DMSMS 2001

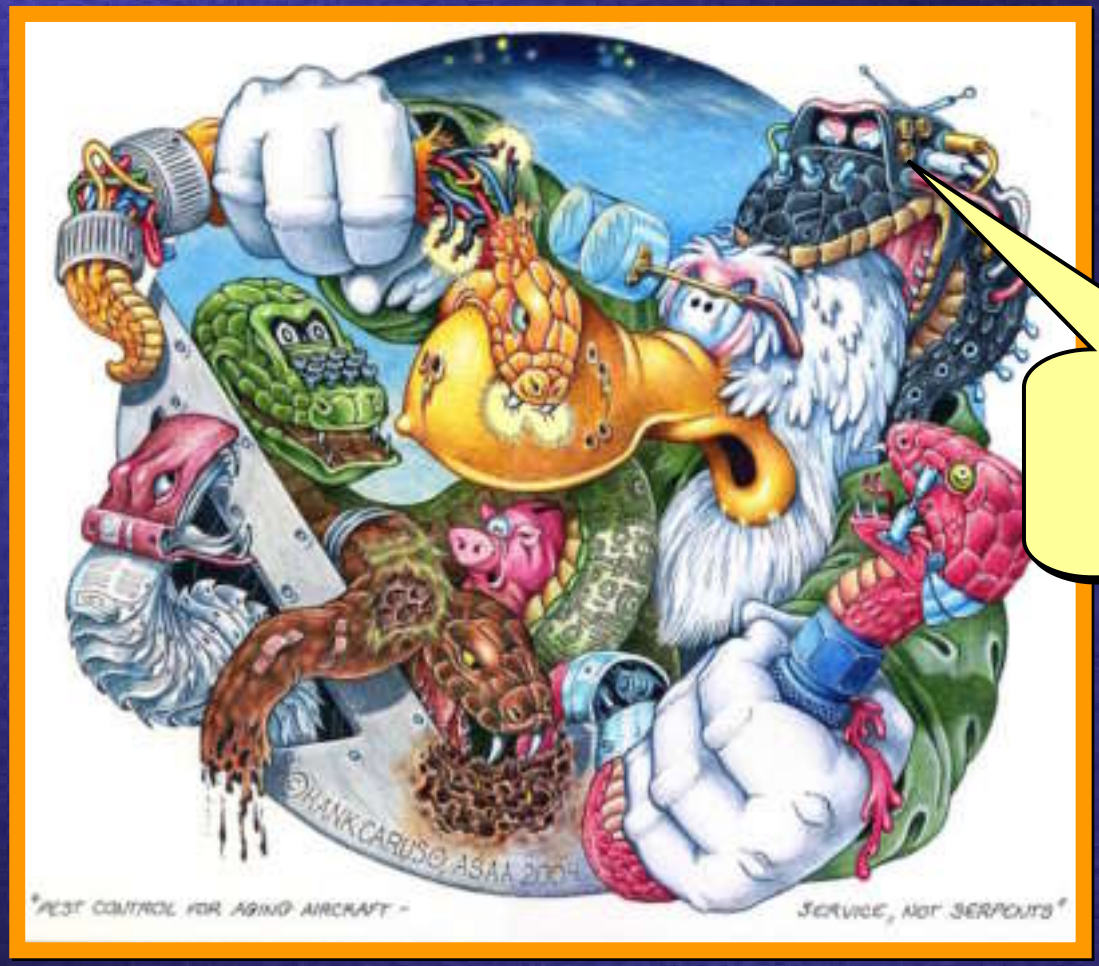
Key Failure Mechanisms

- Design and Manufacturing Defects
  - Layout
  - Metalization
  - Oxide
  - Bonding
- Semiconductor “Wearout”
  - Electromigration
  - Hot Carrier Damage
  - Gate Oxide Failure – TDDB





New unknowns with new processes



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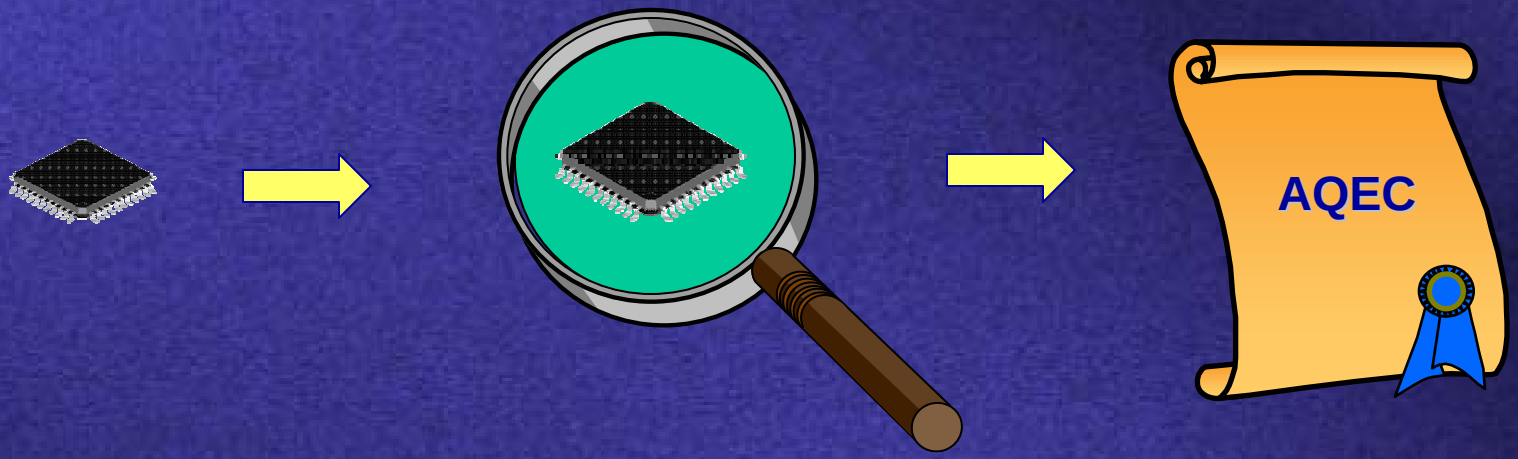
Aerospace Qualified Electronic Components (AQEC)



Start with the device manufacturer's "COTS" component

- ***Assure qualification, quality, reliability, design stability, etc.***
- ***Assess the component's capability to satisfy essential aerospace requirements***
- ***Evaluate part availability and business issues***

If necessary, issue a new part number and data sheet

AQEC Benefits and Status

- Benefits
  - Promotes communication between semiconductor device manufacturers and aerospace industry
  - Minimizes and reduces need for uprating or upscreening
  - Part performance characterized for avionics
  - DMSMS Management
    - Improves part availability
    - Component Roadmaps
  - Improves configuration control
  - Enables system design tradeoffs (performance, lifetime, supply voltage, speed, temperature, etc.)
- AQEC Status
  - AQEC Standard out for vote by GEIA G-12, GEIA APMC, JEDEC JC 13
  - Under consideration by IEC TC 107, Process Management for Avionics

AQEC - Who's Involved ?

DoD:

NAVAIR, DSPO, AWACS, AMCOM, JCAA, DUSD(L&MR)

Airframe Integrators:

Boeing, Lockheed Martin, Northrop Grumman

Avionics OEMs:

Honeywell, BAE, Smiths, Rockwell Collins, Goodrich

Part Manufacturers:

Motorola, AMI, Micron, Texas Instruments, IBM, Intel, Xilinx, National, LSI Logic, Vishay-Siliconix, Linear Technology, Altera, Philips, Analog Devices

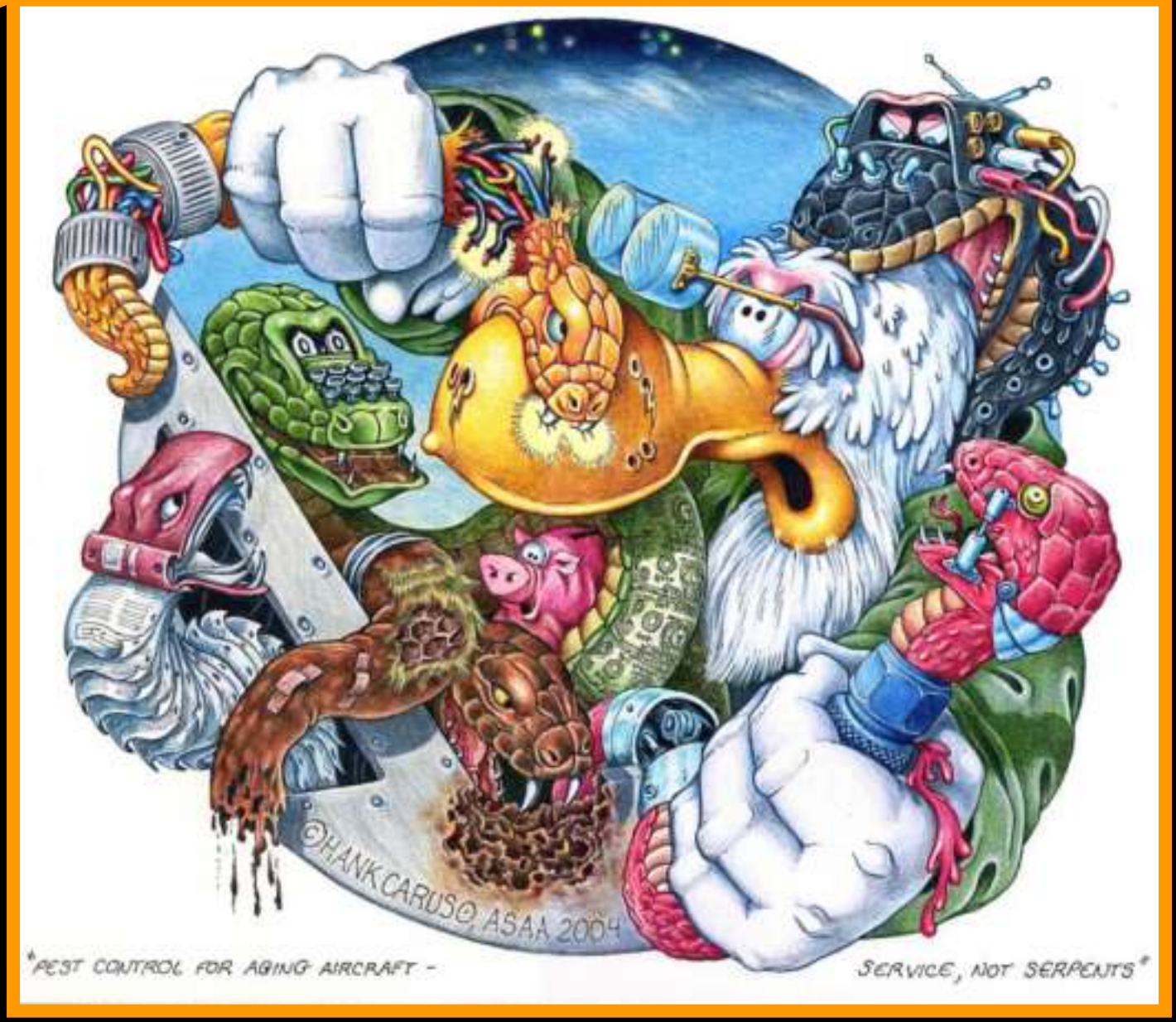
Others:

NASA, FAA, COG, G-12, EIA, SIA, JEDEC, AIA, AVSI, DSCC

Summary

- DoD systems increasingly rely on advanced microelectronics technology
- Significant use of COTS devices since 1995
  - Consumer markets drive the semiconductor industry
- Systems designers must consider new impacts:
  - Lead-free
  - Tin whiskers
  - Atmospheric radiation
  - Semiconductor wearout
  - COTS

Don't let technology bite your



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